OFF THE SHELF TECHNOLOGY FOR GUN BARREL STRAIGHTNESS MEASUREMENT
10TH U.S. ARMY GUN DYNAMICS SYMPOSIUM

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Gun barrel straightness is one of several manufacturing variables that must be held to a specified tolerance. Therefore, barrel centerline measurement is a necessity. In the past, centerline measurement techniques have been developed specifically for this application, and production of such machines has been made on a small quantity basis. This paper will describe the application of an off-the-shelf, three-dimensional laser tracker system, manufactured by Spatial Metrix Corporation (SMX), to measure the bore centerline of a 120-mm tank gun barrel. An introduction/tutorial on barrel straightness terminology, coordinate systems, and the level of precision required for such measurements is presented. A side-by-side comparison is then made between the SMX-based measurement and the standard/conventional measurement of several barrel centerlines, with the pros and cons of each system noted.

INTRODUCTION

It has long been asserted that barrel centerline shape substantially affects gun accuracy. Projectile developers are quick to request and select tubes that exhibit smooth centerlines to ensure the least amount of in-bore disturbance possible to their designs. Tank trainees also desire near-norm centerlines since their qualification tests (tank table tests) could be jeopardized by atypical tubes. Thus, the ability to acquire and access centerline data is important to researchers as well as users.

TERMINOLOGY & METHODOLOGY

Barrel straightness is defined by specifying the path of the barrel's symmetry axis. This can be determined, for example, by measuring the location of a bore-centered target as it moves down the tube. It is common practice to reference the bore centerline to either a line drawn through the center of the bore at its end points, Fig. 1a, or a line drawn through the center of the bore at its support points, Fig. 1b (the latter definition [b] is adopted here). Watervliet Arsenal (WVA) gun centerline measurements are typically done in accordance with Figure 1a. This method is chosen because a maximum bend of 2 mm over the entire length is described by a maximum radius (basically``y'' from the line joining the breech and muzzle

centers) calculation at any one point. Figure 1a shows only the ``y" distance to the centerline as ``x" deviation contributions are typically much smaller.

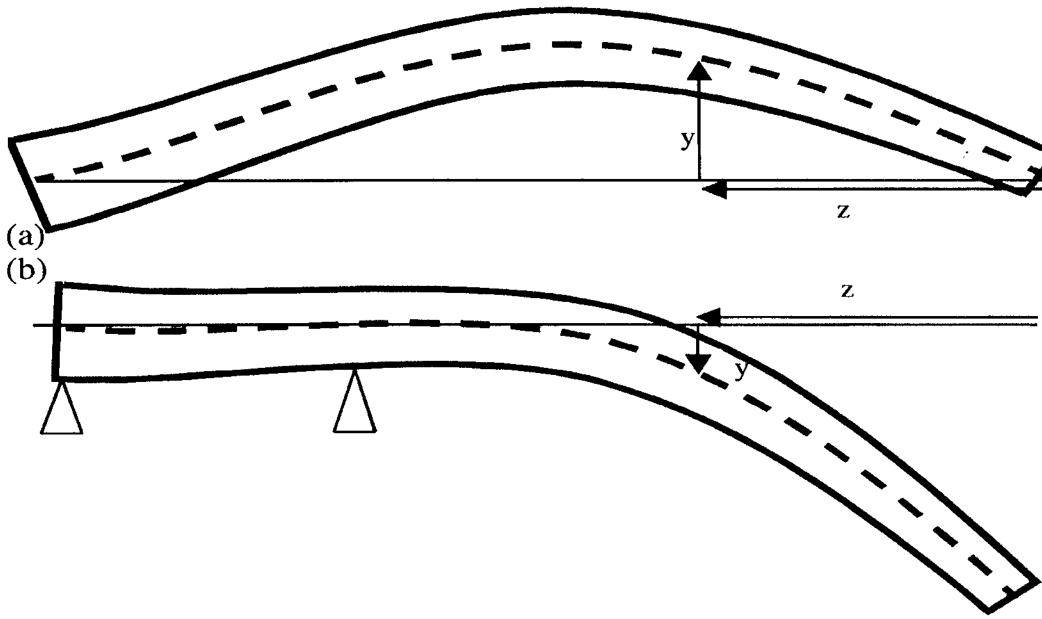


Figure 1. Two Methods of Specifing Barrel Curvature: (a) Relative to a Line Through the First and Last Bore Center Measurements, or (b) Relative to a Line Through the Bore Center at Its Support Points.

Barrel centerline measurements must account for gravity effects as well as nonstraightness of the bore. These attributes are separated by subtracting measurements of the tube at 12 o'clock and 6 o'clock orientations. The difference is the barrel centerline. The removal of the centerline deviations from a measurement reveals the gravity effects or , "droop" as it is termed. Tube measurements are taken every 200 mm. A barrel acceptance criteria states that the tube centerline, excluding droop, must not vary by 0.5 mm over a 600mm distance, or by 2 mm over the entire length of the tube (1,2). These criteria created the need for a coordinate system that is easily understood and descriptive. The result was simply to have a translating "X-Y" (2-D) coordinate at each measurement location. Positive Y is upward and positive X to the right. A self-centering target is moved down the tube and its displacement from a virtual perfect centerline noted. Measurements are performed with the tube held in the same manner as in the tank. These zero points are located at 670 and 1850 mm from the rear face of the tube. Neither the Aberdeen Test Center (ATC)or WVA measurements include the chamber area and are simply for the projectile travel length. The centerline plots, such as Figure 1, begin at 230 mm (near the muzzle) and end at 4630mm (near the bore start). Unfortunately, ATC measurements are taken in reverse of WVA as their measurements begin near bore start and end near the muzzle. ATC has adhered to making measurements in the

same bore locations as WVA for easy barrel comparison and the figures presented follow this convention. ATC protocol is to take 3 measurements and use an average. As noted, the straightness measurements are composed of X and Y displacements as the measurement devices move down the tube. The selected figures that follow simply give ``Y" measurements, since the elevation plane is where the largest deviations are commonly measured.

OPTICAL CENTERING TECHNIQUE

An older method for estimating gun tube straightness is the optical method (3). This method requires an alignment telescope and a backlit target on a bore-riding carrier. This method's accuracy is largely dependent on the skill of the operator. The optical method is time consuming due partially to setup. The error involved is most easily reduced by averaging measurements. Figure 2. is derived from a set of optical measurements. The differences in the passes for the elevation graph are primarily caused by differences in resolving the motion of the target. The differences between the graphs are on the order of 0.10 mm (.004 inches).

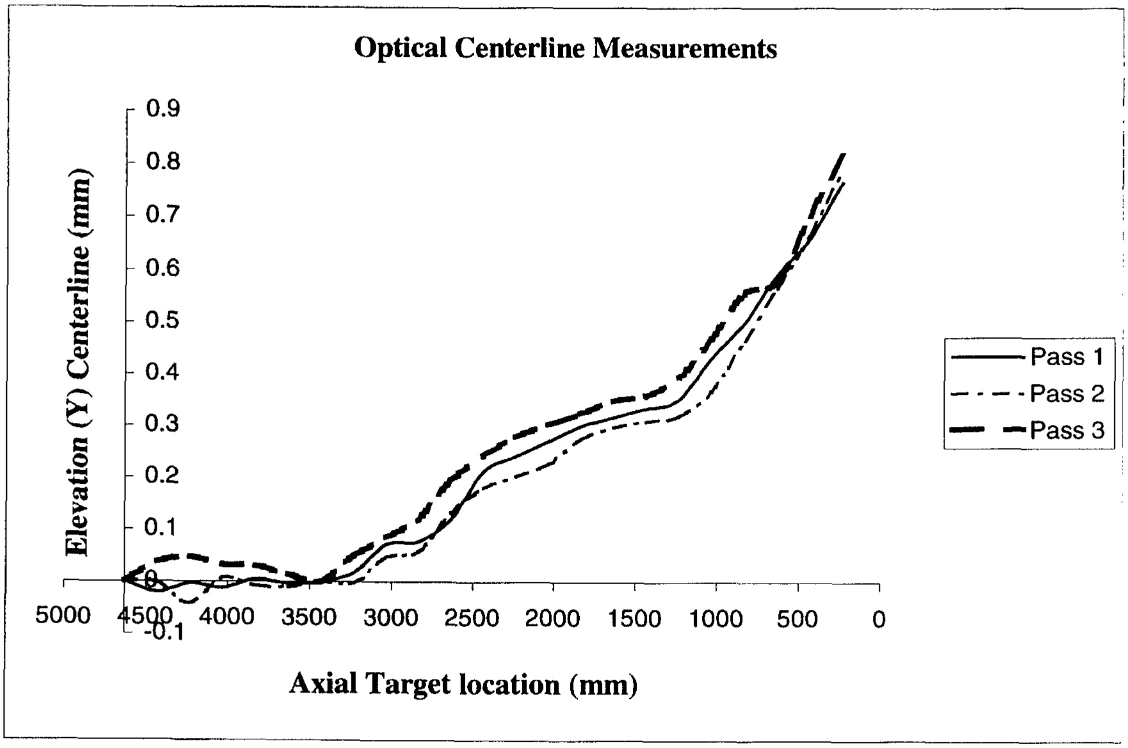


Figure 2. Typical tube centerline elevation (Y) deviations using the optical method.

A step toward reducing the operator influences is offered in the Gun Tube Inspection Station (GTIS) method.

GTIS MEASUREMENT TECHNIQUE

The 120mm tank gun tube straightness is initially measured with a laser device, known as the GTIS (located at the manufacturing plant in Watervliet Arsenal, NY) (4,5,6). These measurements involve sensing the location of a laser spot on a target and the motion of

the target relative to the reference laser beam, as the target moves down the bore. The laser emitter fixture and the target are initially aligned (to establish a reference centerline) at the muzzle and bore start. The target resolution, as to where the laser beam strikes it, is governed by the amount of pixels the target has and the spread of the beam. Ascertaining where the beam strikes the target requires the determination of the center of the beam. While the laser beam is a focused source, its spread at distance dictates that an averaging procedure be used to compute where the beam center actually is. This equipment generally produces consistent results. Unfortunately the system requires warm-up over the course of 20-30 minutes. Measurements done before this warm-up period is complete show a bias not found in later readings. Concerns have also been expressed as to inaccuracies occuring from a rotation of the target head as it traverses the barrel. These are small but nonzero. Operator error is generally minimized over the optical method. One drawback of the GTIS equipment is that it has shown maintenance deficiencies. This state of affairs forced ATC to use the optical method more frequently than the GTIS equipment. Figure 3 shows a set of GTIS measurements for an L55 barrel.

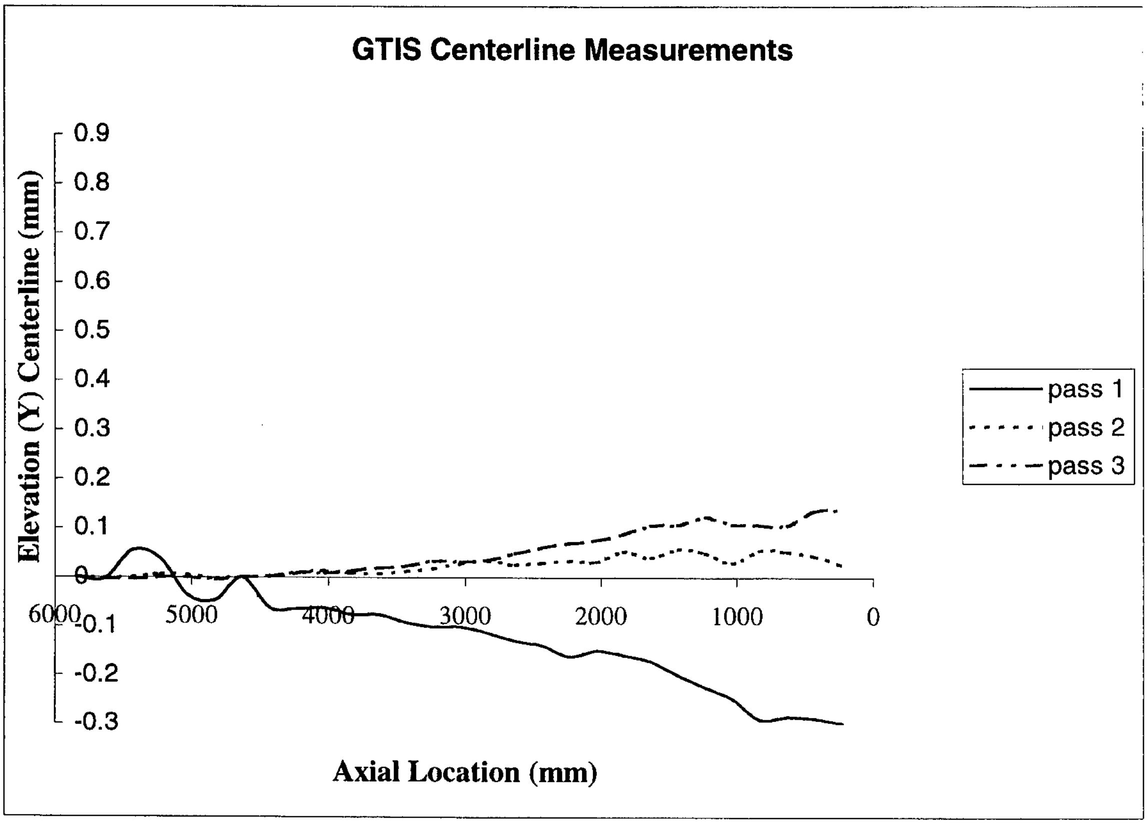


Figure 3. GTIS Centerline Elevation Measurements on an L55 barrel.

SMX MEASUREMENT TECHNIQUE

The Spatial Metrix (SMX) laser metrology system offers a host of improvements over the current gun tube measurement methods. A picture of the system is shown in Figure 4. The system uses a single tracking head which follows a Spherically Mounted Reflector

(SMR). This is opposed to laser based triangulation methods that require the setup of 2 receiving heads. The setup for the SMX system requires environmental conditions of over 40 and below 110 F (7). These restrictions are based on the ability of the equipment to modulate the laser beam such that it produces a constant wavelength of light. Operator checks are also required to assure that angular measurements and optical return power levels are satisfied.
Checks for point closure (the ability to remeasure a point and get the same value as that obtained previously) are easily performed by returning to measured points and noting differences (if any) from prior measurements. Tolerance levels can be input to warn of potentially inaccurate readings. These setups and verifications take approximately 20-30 minutes to perform. The SMX system uses interferometry measurements from the laser beam returns to determine the location of the SMR. The SMR is positioned in a fixture mounted to the same self-centering target apparatus used in the optical method discussed previously. Centering of the SMR on the target is done once by the centering of a nest, in which the SMR rests. During measurement, the SMR is moved to the preset axial locations used under the GTIS and optical measurement practices, and measurements are taken. Because the receiving head of the SMX system tracks the SMR's motion it continously measures location at a 1 kHz rate. It records this data when instructed and then averages the most recent

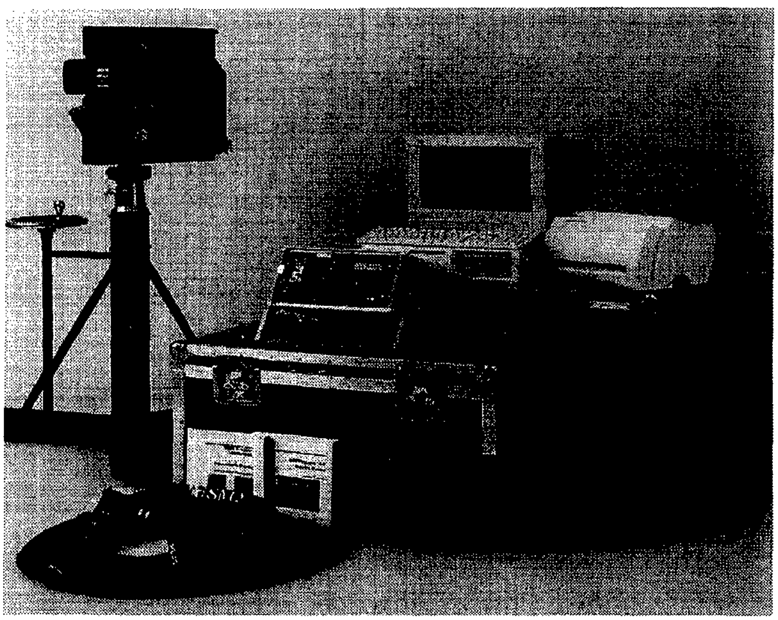


Figure 4. The SMX Tracker 4500 metrology system.

measurements to minimize the effect of spurious readings. Accuracies of approximately .0001 inch are realizable when measuring centerlines with the SMX system. This compares to a .001 inch accuracy using the optical method. Recording data with the SMX system simply requires the push of a button once the SMR is located at the desired measurement points. The burden of having to optically judge the change in location of the target center is removed, and the operator's biggest concern is assuring that readings occur at the proper axial points. Making centerline measurements in this manner (once the system is setup) is a 5 minute process. Other data acquisition techniques using the system may further reduce the measurement time to less than a minute. These techniques have not been pursued to date. A

comparison with previous methods is more obvious when axial measurement points are identical, and this temporarily precludes the use of the advanced method. These more advanced techniques also require slightly more familiarization with the system. They will eventually be employed. The removal of the judgement of target motion has also tremendously increased the repeatability of the measurements. This makes the system equally effective to all users with reasonable skill. Perhaps the best feature of the new measurement technique is the removal of pencil and paper for recording measurements. The measurements are stored electronically and are readily transferable to graphing packages for review. Furthermore the data is easily transferable via electronic means to interested parties. The elimination of computer data entry to facilitate dispersal is key to speeding the process and eliminating human error. Perhaps the most daunting attribute of the system is the $145,000 cost. This cost is easily offset in the amount of time saved in measurement, and data transmission and manipulation. New system costs are always a changing attribute as they typically drop over time as a technology becomes more accepted. The choice of accessories also impacts the cost of the system.

While other tasks are not discussed here, there are many other uses. The portability of the system and its ease of use make it ideal for accurate test instrument location surveys, fragment dispersal, damage measurements, and rapid contour and part characterizations as well. These uses also potentially offset the high cost.

Figure 5a offers the same graph shown in Figure 2. with the SMX data set superimposed for easy comparison to previous data set. The SMX data falls within the envelope of the optical measurement plots and is so repeatable that variations between passes are difficult to detect. The repeatability of the data is shown in Figure 5b. Small differences can be detected but these may arise from not matching axial location perfectly.

Figure 5a. Comparison of Optical measurement technique to SMX method.

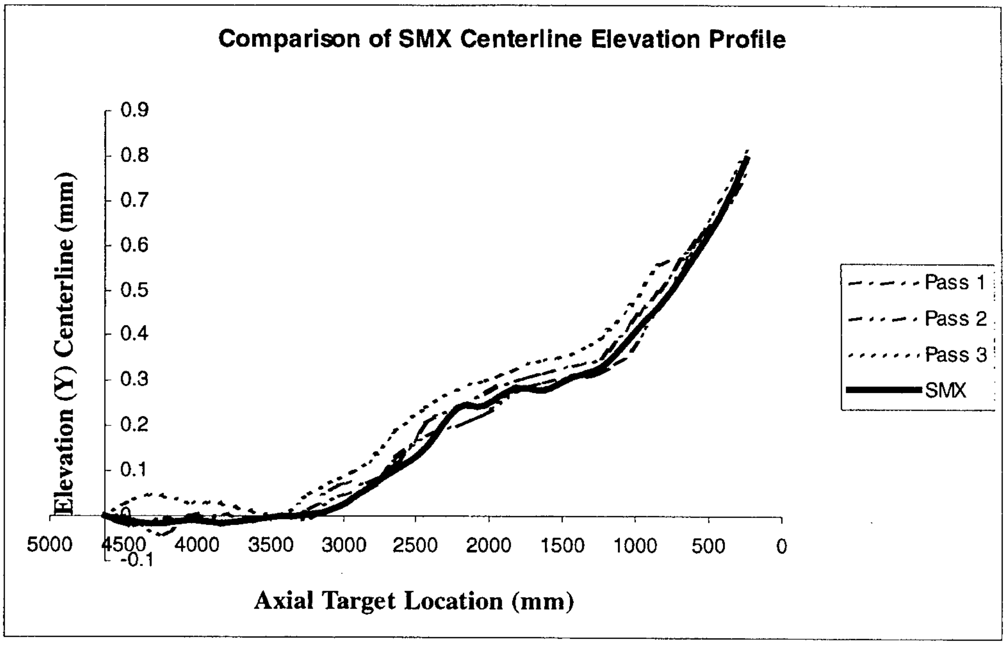
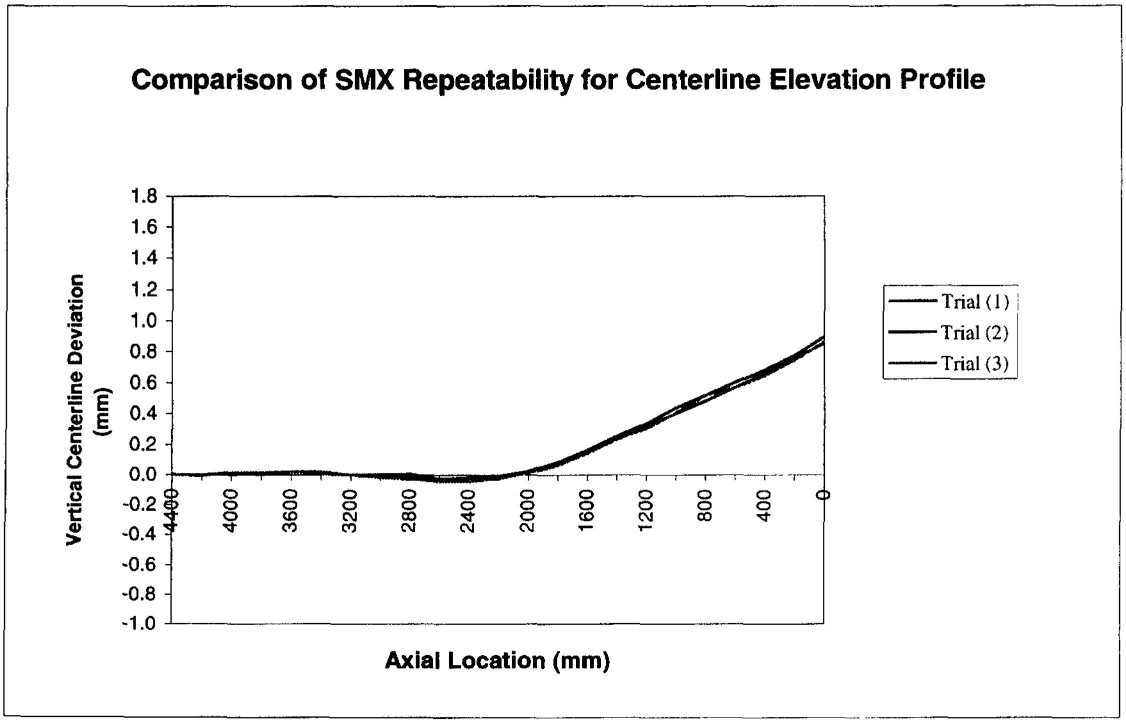


Figure 5b. Comparison of Repeatability of SMX method.



The difference detectable is perhaps .01 mm Lastly the maintenance required for the SMX system is a once per year cleaning and "tuning" of the optics and electronics. Spare parts (such as extra SMR's) are included as desired in the purchase package. SMR's generally get damaged as they are handled most frequently.

CONCLUSIONS

The SMX system is a significant advancement in the science of measuring gun tube centerlines. It conservatively allows bore measurement to proceed 10 times faster with a similar advance in data processing speed and distribution. The repeatability of the SMX system almost argues against doing more than one pass, though multiple passes are still performed to add an increased level of certainty to the data (multiple passes are also reasonable in light of the fact that each pass takes only 5 minutes). The SMX system's ease of use should expand the potential set of users as well. Enhancements to allow the measurement of tube diameter at axial locations with the SMX system are also in process. Despite the SMX system cost, it is a worthwhile step forward in accurately measuring gun attributes.

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